

Initialization of Tropical Cyclone Structure for Operational Application

PI: Tim Li

IPRC/SOEST, University of Hawaii at Manoa
1680 East-West Road, POST Building 409B
Honolulu, Hawaii 96822

Phone: (808) 956-9427 fax: (808) 956-9425 e-mail: timli@hawaii.edu

Co-PI: Melinda S. Peng

Naval Research Laboratory
Monterey CA 93943-5502

Phone: (831) 656-4704 fax: (831) 656-4769 e-mail: melinda.peng@nrlmry.navy.mil

Award Number: N000141010774

LONG-TERM GOALS

The long-term goal of this project is to improve the prediction of tropical cyclone (TC) genesis, structure and intensity changes through improved representation of 3-dimensional TC structure at the initial time. The accurate prediction of TC genesis, structure and intensity changes is critical to Navy missions and civilian activities in coastal areas. Significant gains have been made in the TC track prediction over the past decades. The genesis and intensity forecast, however, has shown very little progress during the same period. A main factor contributing to lack of skill in the prediction of TC genesis and intensity is the inadequate representation of initial axisymmetric and asymmetric TC dynamic and thermodynamic structures. TC initialization is a universal problem in nearly all current operational weather forecast systems, as indicated in a recent HFIP workshop. By conducting both idealized Observation System Simulation Experiments (OSSE) and real-case TC forecast experiments, we intend to tackle the weaknesses faced in current operational weather forecast models.

OBJECTIVES

The objective of this project is to develop a new initialization scheme to improve the representation of 3-dimensional TC structures in operational weather forecast models.

APPROACH

We propose a combined TC dynamic initialization-3DVar data assimilation approach. The key component of this new scheme is a TC dynamic initialization (TCDI) package. The TCDI package includes three steps. The first step is the decomposition of the TC vortex from its environmental field. The second step is a dynamic initialization with the full nonlinear dynamics and physics, which forces the first guess field toward the observed central minimum pressure, given realistic asymmetric heating profiles. The third step is to add the newly generated TC field into the environmental field and used it

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 30 SEP 2011		2. REPORT TYPE		3. DATES COVERED 00-00-2011 to 00-00-2011	
4. TITLE AND SUBTITLE Initialization of Tropical Cyclone Structure for Operational Application				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Hawaii at Manoa,IPRC/SOEST,1680 East-West Road, POST Building 409B,Honolulu,HI,96822				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 4	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

in the subsequent 3DVar assimilation. After the TCDI is completed, the 3Dvar assimilation further follows. A preliminary OSSE study was conducted and the result showed that this new approach greatly improved both TC symmetric (such as TC intensity and warm core structure) and asymmetric dynamic and thermodynamic patterns.

WORK COMPLETED

Observation System Simulation Experiments with aid of the WRF model and its 3DVAR assimilation system have been done to demonstrate the usefulness of the combined TC dynamic initialization-3DVar scheme. A manuscript entitled “A 3DVAR-based Dynamical Initialization Scheme for Tropical Cyclone Predictions” was submitted to the *Weather and Forecasting*.

RESULTS

Two major US operational TC forecast systems at Navy Naval Research Laboratory/ The Fleet Numerical Meteorology and Oceanography Center (NRL/FNMOC) and NCEP apply different TC initialization schemes, respectively. The Navy Operational Global Atmosphere Prediction System (NOGAPS) includes synthetic data to represent TC vortex treated as convective dropsonde data, while the NCEP global forecast system (GFS) uses a relocation method without adding synthetic data. Regardless of the difference in the initial wind field of TCs between the two operational forecast systems, both have a much weaker initial TC MSLP compared to the observed. For instance, for Atlantic hurricane Francis (2004) (which caused devastating damage in Florida), when the observed MSLP reached 940 hPa on September 1, the NCEP analysis had a minimum pressure of 998 hPa whereas the NOGAPS analysis showed a MSLP of 992 hPa. Given such a large bias in the initial MSLP, the TC intensity forecast error was also quite large.

It is worth mentioning that during the update data assimilation cycle, the initial TC MSLP was provided by the best track information into the operational 3DVAR assimilation systems for both models. Why does the current 3DVAR data assimilation system incapable of preserving the observed MSLP information? We intended to look into the problem through a series of observation system simulation experiments (OSSE), using the Advanced Research Weather Research and Forecast (WRF) model (ARW; Michalakes et al. 1999, Skamarock et al. 2005), and its 3DVAR assimilation system (Barker et al. 2004a,b). An examination of the WRF 3DVAR code indicates that a transfer from standard-pressure level fields to those in a sigma vertical coordinate without the knowledge of actual TC central minimum pressure value is the part of the problem. For example, in some strong typhoon cases the differences between the observed MSLP and first guess MSLP can be as large as 50 hPa. Such a difference may lead to significant large biases in the dynamic and thermodynamic fields near the TC core. In addition, an application of a general geostrophic wind-pressure relation in the 3DVAR constraint is another possible cause. Uncertainty in the background and observation error covariance is also a possible cause.

Our strategy is to improve the first-guess field prior to 3DVAR so that the errors associated with the pressure-to-sigma coordinate transfer can be minimized. Based on the findings and consideration mentioned above, we develop a TC dynamic initialization (TCDI) scheme. The TCDI package consists of a primitive-equation system with full nonlinear dynamics and physics. Prior to TCDI, the first guess field is decomposed into a TC vortex and its environmental field, following Kurihara et al. (1993).

Then we integrate the third version of Tropical Cyclone Model (TCM3, Wang 2001) with the decomposed TC vortex as an initial condition. During the integration, the weak vortex is forced toward the observed MSLP by adding a Newtonian damping (restoring) term in the surface pressure tendency equation.

The OSSE experiments demonstrated that this new initialization strategy can lead to a much improved initial MSLP, warm core and asymmetric temperature patterns, compared to that from the conventional 3DVAR scheme (see Zhang et al. 2011). The forecast of TC intensity with the new initialization scheme was conducted, and the result showed that the new scheme is able to predict the “observed” TC intensity change, compared to runs with the conventional 3DVAR scheme or the TCDI-only scheme (Fig. 1). Sensitivity experiments further show that the intensity forecast with the knowledge of initial MSLP and wind fields appears more skillful than the case when the knowledge of initial MSLP, temperature and humidity fields are known. The numerical experiments above demonstrate the potential usefulness of the proposed new initialization scheme in the operational application.

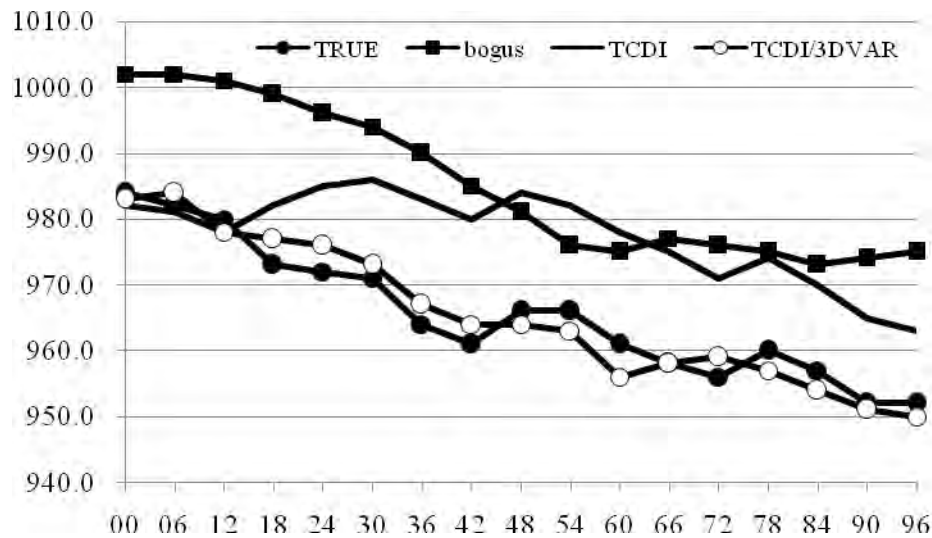


Fig. 1 96-hr forecasts of the TC minimum sea-level pressure (MSLP, unit: hPa) with an initial condition from a weak Rankine vortex (close square), the new TCDI/3DVAR initialization scheme (open circle) and the TCDI-only scheme (solid line). The “observed” pressure evolution from the OSSE is denoted by close circle curves.

The OSSE study above demonstrates the potential usefulness of the new TCDI/3DVAR scheme in the operational application. A preliminary application of the new initialization strategy to the Navy operational TC forecast model, COAMPS-TC in 2008-2009 summers was conducted and the result is encouraging.

IMPACT/APPLICATIONS

The improved representation of initial TC state may lead to a more skillful prediction of TC genesis and intensity change.

TRANSITIONS

The proposed TC initialization scheme has been transferred to NRL for intensive offline test using the NOGAPS and COAMPS-TC models. Once proved to be useful, the TC dynamic initialization scheme will be transitioned into the navy operational systems.

RELATED PROJECTS

This project is complimentary to the ONR funding entitled “Analysis and high-resolution modeling of tropical cyclone genesis during the TCS-08 field campaign” in which we investigate the dynamics of TC genesis using a cloud resolving model and conduct western Pacific TC reanalysis during the period of TCS-08 observational campaign.

PUBLICATIONS

The following are papers published in the last fiscal year that are partially supported by this grant:

- Li, T., 2011: Synoptic and climatic aspects of tropical cyclogenesis in western North Pacific. in *Cyclones: Formation, triggers and control*, edited by K. Oouchi and H. Fudevasu, Noval Science Publishers, in press.
- Hong, C.-C. Y.-H. Li, T. Li, and M.-Y. Lee, 2011: Impacts of Central Pacific and Eastern Pacific El Niños on tropical cyclone tracks over the western North Pacific. *Geophysical Research Letters*, in press.
- Gao, J.-Y., and T. Li, 2011: Factors controlling multiple tropical cyclone events in the western North Pacific. *Mon. Wea. Rev.*, in press.
- Zhou, X., B. Wang, X. Ge, and T. Li, 2011: Impact of secondary eyewall heating on tropical cyclone intensity change during eyewall replacement. *J. Atmos. Sci.*, in press.
- Li, T., M. Kwon, M. Zhao, J. Kug, J. Luo, and W. Yu (2010), Global warming shifts Pacific tropical cyclone location, *Geophys. Res. Lett.*, 37, L21804, doi:10.1029/2010GL045124.

Manuscript in revision:

- Zhang, S.-J., T. Li, X. Ge, M. S. Peng, and N. Pan, 2011: A 3DVAR-based dynamical initialization scheme for tropical cyclone prediction. *Wea. Forecasting*, in revision.